AIR SHOCK INTENSITY AT GRANTSVILLE, UTAH RESULTING FROM FIRING ON THE DEMOLITION RANGE AT TOOELE ORDNANCE DEPOT

BY

MELVIN A. COOK & WILLIAM S. PARTRIDGE

NONTECHNICAL MEMORANDUM

DECEMBER 15, 1952

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INSTITUTE FOR THE STUDY OF RATE PROCESSES

EXPLOSIVES RESEARCH GROUP

UNIVERSITY OF UTAH

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University of Utah Explosives Research Group

During the summer of 1950, Dr. Gordon L. Bell made a geological study of the region in and surrounding the Tooele Ordnance Depot and recorded the strength of both air and ground shocks in Grantsville and Tooele resulting from demolition charges of various sizes fired on the demolition range. At Grantsville, six and one-half miles from the demolition range, he detected no ground shock but recorded air shocks of intensity up to 84 decibels. The failure to observe ground shock at such large distances from the demolition range is quite understandable. In fact, seismic waves are not objectionable more than a half mile from shots of the size studied by Dr. Bell even when made entirely underground rather than on the surface. Since the time of these studies, the residents of Grantsville and Tooele have complained at various times that the air disturbance from demolition shots have been objectionable, being much stronger at certain times of the year than at others. Dr. Bell's recommendations included restricting the use of the range to days when the "ceiling" was greater than 5000 feet. Although this recommendation has been followed, large variations in the strength of the shock waves striking Grantsville are still observed even on consecutive cloudless days when the weather conditions have appeared practically identical. Since this problem is one of general interest and one that might eventually affect the University of Utah Explosives Group directly, since they are also using the T.O.D. demolition range, it was decided that this group should carry out a limited investigation of the air blast problem surrounding T.O.D. It was evident that tests of this sort could be conducted without appreciable cost to the University by making use of equipment already available to them from their own projects and from

T.O.D. Moreover, it was necessary anyway for "Utah Project" investigators using the demolition range for research purposes to leave the demolition area when the demolition shots were being fired. Very little additional inconvenience was incurred, therefore, to carry out measurements of the air blast in Grantsville and the surrounding region. While the desired objectives were reached by the work reported in this nontechnical memorandum, studies of air blast in this region will be continued whenever conditions exist where it appears that beneficial results will be obtained, since they do not entail appreciable time loss and cost.

The objectives of this study were (1) to measure the strength of the shock waves striking Grantsville, (2) to determine why seemingly identical weather conditions gave varying shock intensities in areas near the depot, and (3) to recommend measures to be taken to reduce the intensity of these disturbances.

Equipment

Tooele Ordnance Depot owns a Western Electric sound level meter, model 700A and an Esterline-Angus recorder, which was used by Dr. Bell in the original investigation. This equipment was supplied to the present investigators but could not be used to record sound intensity, since the recorder had a ten millivolt movement and the meter in the sound level meter had a fifty microvolt movement. This means that the maximum output of the amplifier in the sound level meter would only deflect the recorder one-fifth of its travel. But, more serious, it would be impossible to determine what the readings on the recorder represented in terms of decibel units. Therefore, the sound level meter was used without a recorder. This was done by visually observing the maximum deflection of the decibel meter when the shock wave hit.

This sound level meter does not indicate the peak intensity of a sound wave, but rather an average value. The simplest method available to measure the peak intensity was to use an oscilloscope which in effect plots the intensity of the wave against the time. This method was used, employing a Dumont model 303A oscilloscope and a calibrated microphone to pick up the sound wave and feed it into the scope. Figures 1, 2, and 3 show the type traces obtained. The wavy line is, in effect, a photograph of the sound wave over a period of approximately one second. The vertical deflection on the oscilloscope is determined by the voltage generated by the sound wave, that is, the more intense the sound wave, the larger the voltage it will generate and the greater will be the deflection on the face of the oscilloscope when it is photographed. The two dotted lines show the deflection from a voltage of 0.025V ~~0.28~~ volts. To find the peak intensity of the sound wave, one must measure the vertical distance between the highest "peak" and the lowest "valley" of the trace and compare this distance with the calibration trace obtained by 0.025V ~~0.28~~ volts. In this way, one can find the voltage generated by the sound wave after it strikes the microphone. Figure 4 gives the calibration curve for this microphone from which one can find the intensity corresponding to the voltage generated by the shock wave.

All the intensity levels reported here were taken with the sound level meter, but on one test, the sound level meter and the oscilloscope were used to record simultaneously the intensity of the sound waves striking near the Grantsville Seminary building. The results are shown below:

Pit No.	TNT Per Charge	Deflection	Intensity (from scope)	Intensity (sound level meter)
1	402 lbs.	----	----	85 db
2	460 lbs.	.0066 volts	90 db	83 db
3	460 lbs.	.0134 volts	96 db	90 db
4	460 lbs.	.0134 volts	96 db	86 db
5	460 lbs.	----	----	75 db
6	460 lbs.	.0378 volts	104 db	96 db
7	460 lbs.	.0267 volts	101 db	95 db

It appears from these results that the peak intensity is approximately 5-10 db greater than the intensity indicated by the sound level meter. Since a decibel is a logarithmic unit, this means that the shock wave is 2-3 times as strong (energywise) as that recorded by the sound level meter.

Temperature soundings of the atmosphere above the depot were taken by Harold England from Dugway Proving Grounds by using meteorological equipment on an airplane to take temperatures at the indicated levels.

Results and Discussion

The effect of weather conditions on propagation of air shocks at large distances from explosions was studied extensively by Dr. Everett F. Cox and a paper presented by him at the June 25, 1952, Salt Lake City meetings of the Fluid Dynamics Division of the American Physical Society. He reported that varying weather conditions alone brought about signal ratios as large as 3200 to 1, recorded at a single microbarograph station when identical charges were fired at the same location at different times. Moreover, he discribed some of the more important factors leading to these variations, including the influence of "temperature inversion".

The blast waves from an explosion radiate in all directions. For a shot above ground, if the temperature of the air were constant and there were no wind or clouds, the blast waves would travel away from the source following spherical expansion. Under ordinary conditions, the temperature of the atmosphere decreases approximately three degrees centigrade (3°C.) per thousand feet increase in altitude. This situation tends to bend blast waves up away from the ground as they travel outward from the point of origin. Unfortunately, this situation is not always found. Sometimes the air is warmer one to two thousand feet above the ground than it is on the surface, a situation which the meterologists call "temperature inversion". Under these conditions, a sound wave traveling outward from the source is bent back toward the ground level, and since it travels faster in warm than cold air, there exists a possibility of reinforcing the waves propagating along the surface and thus concentrating the air blast intensities at various points along the surface.

Another factor of importance is wind direction and magnitude. Blast wave intensities tend to be enhanced in the direction of the wind, and diminished in the opposite direction. This factor, however, was not studied in this work since it is already moderately well known and has been described elsewhere. It is also well known that overcast conditions and heavy, low-lying clouds tend to reflect air blast and intensify it at the surface. It was clear that none of these factors, however, were responsible for the difficulties encountered with residents at Grantsville. As a matter of fact, on several occasions it was observed that when the wind was blowing toward Grantsville from the demolition range, the shot intensity was less than when it was blowing in the opposite direction. The reason for this strange condition was later found to be the fact that winds in the direction toward Grantsville would tend to blow the cold air mass back over the Great Salt Lake thus removing the "temperature inversion", whereas winds in the opposite direction would blow it into the valley. Thus the increase in blast intensity due to the "inversion" apparently then more than off-set the decrease due to the wind direction. However, one must also know wind directions at various levels above the surface to be sure that this is the case; differential winds, for example, can also act in a manner similar to "temperature inversion".

During the spring and fall, "temperature inversions" are quite common in Salt Lake Valley. During periods when weather conditions are such that there are very few winds, the cool air from the surrounding mountains "flows" into the valley and sometimes stays there for days. This usually occurs in the fall, winter, and spring months since the stronger heating of the earth's surface, which takes place in the summer, burns out any "inversion" that forms during the cooler summer nights. During the colder part of the year, a layer of smoky air is often very prominent in the lower elevations above Salt Lake. When this condition exists, a cold air mass fills the lower layers of the valley leaving warm air above it. Such a condition existed on October 29, 1952, when the shock intensity from demolition charges was objectionable. Figure 5 shows a plot of the temperature versus altitude above the demolition range made in the morning and also the afternoon of that day. A definite "inversion" was found at both times at about 1400 feet elevation. Figure 6 gives the temperature cross section of the "inversion" and shows that the top was fairly flat and did not follow the contours of the terrain. On November 7, 1952, another temperature sounding was taken and the results are shown on Figure 7.

On some days there were strong winds (15-20 mph) from the south during the morning followed by a slight breeze (3-5 mph) from the north in the afternoon. The winds in the morning blew the cold air mass out of that end of the valley, thus destroying the "temperature inversion", and shots fired at the demolition range caused no trouble at Grantsville. However, in the afternoon the breeze was caused by the cold air mass flowing back in from over the lake and as soon as the "inversion" had reformed, the air shocks experienced in Grantsville were from three to four times as strong as in the morning.

Grantsville is located six and one-half miles almost due north of the demolition range. Sound propagated over flat terrain will decrease in intensity at the rate of approximately seven decibels every time the distance from the point of origin is doubled. The solid line in Figure 8 shows this decay rate on a scale which shows the position of Grantsville. It will be noted that on days when there was a "temperature inversion", the intensities recorded were fairly close to the theoretical curve, but on days when there was no "inversion", the intensities were much less than the theoretical values. The normally much lower intensities are due to the physical location of the demolition pits in a valley which places a natural barricade between the explosion and the town of Grantsville. Also, the demolition range is about 600 feet higher than Grantsville, which will increase the tendency of a shock wave to pass over the town, except when it is reflected back down by a reflecting layer in the atmosphere, i.e., a "temperature inversion", or a low "ceiling".

The strongest shock wave observed in Grantsville had an intensity of 97 decibels (sound level meter). This corresponds to a peak pressure of roughly one pound per square foot. Allowing a factor of five, the the greatest pressure exerted by a shock wave on the external surfaces of a building in Grantsville would be less than five pounds per square foot. A pressure of about thirty pounds per square foot or more, however, is required to break ordinary glass windows, a pressure of about

100 pounds per square foot to do minor damage to average buildings, and 300 pounds per square foot or more to do serious structural damage to average buildings. Thus even windows should not be broken more than four miles from shots the size of those made at T.O.D. unless they were improperly installed. However, if window frames were poorly constructed, e.g., if the glass were placed in the frame so that a light push from the inside might dislodge it, pressures of about five pounds per square foot might push it out and, of course, probably break it on striking the ground. This situation was reported by Cox. Moreover, objects placed in a mechanically metastable condition might be upset by such a blast, e.g., as they would be under the influence of a gust of wind.

The location of the firing pits in the demolition range with respect to the surrounding hills seems to have a noticeable effect on the shock strength at Grantsville. The following table shows the average intensities recorded in Grantsville for each firing pit. These values have been corrected to equal loads in terms of TNT equivalents.

Pit No.	Average Intensity, db (sound level meter)
1	—
2	76
3	80
4	82
5	79
6	90
7	90

It will be noted that shots fired from pits six and seven caused the greatest disturbance. This was because these two pits are located in the center of the valley and do not, therefore, take proper advantage of the natural barracading. Pits two and five, on the other hand are located closer to the edge of the valley so that the hill makes a better barricade between them and Grantsville.

It had been the practice to fire the demolition charges at five minute intervals to avoid any possibility of interaction of the primary shock wave with any reflected shocks. During the time that these tests were being conducted, no reflected shocks were observed. The only blast wave that struck Grantsville or the main gate of the Ordnance Depot came at 30 to 32 seconds after the shot was fired. With this in mind, it would probably be advisable to fire the charges at much shorter intervals, perhaps in the neighborhood of one minute.

It might be well to point out that on days when there is a "temperature inversion" in Tooele valley, the blast waves that strike Grantsville sound quite loud. It should, however, be emphasized that in spite of their loudness, no damage to a well-constructed building should result from blast waves of the intensity of those observed during this investigation. Though they sound loud, the ear does not actually measure pressure very accurately. The sound level from the strongest blasts measured at Grantsville was only 12 db. greater than was measured at the side of the Seminary building due to heavy trucks passing along the highway. (Maximum sound level 85 db. two trucks passing in front of Seminary) Heavy trucks, moreover, are more likely to cause damage to buildings by means of ground vibration than 1000 lbs. of explosives 6-1/2 miles distance. As a matter of fact, Grantsville is periodically experimenting gusts of wind and earth tremors that are potentially much more destructive than the blasts from the demolition range.

In order to obtain an idea of what is to be expected from blasts of the size of the largest ones being detonated on the demolition range at T.O.D., Figure 9 presents a graph constructed from scaling laws and experience in the explosives industry based on accidental explosives and wartime damage. This graph was computed from data summarized by C. S. Robinson ("Explosives, Their Anatomy and Destruction", McGraw Hill Company (1944)), using the "law of similitudes" for scaling. According to data shown in Figure 9, the only possibility for damage from shots fired on the demolition range would be of the type mentioned above, namely glass breakage in improperly constructed windows, or dislodging of objects mounted or situated in very unstable conditions. It should be noted also that the average limits shown in Figure 9 are based on no barricading. For artificial or natural barricades, such as is afforded by the tarrain of the demolition range, destructive distances are substantially reduced. Incidentially, the law of similitudes is equivalent to the "cube root law" which states that blast intensities vary as the one-third power, or cube root of the (equivalent) weight of explosive used.

Conclusions and Recommendations

1. During the summer months, and at other times when no "temperature inversion" is present over the Ordnance Depot, the shots fired on the demolition range ordinarily will not cause trouble in Grantsville unless other conditions exist to enhance the blast wave in the direction of Grantsville, e.g., high winds, overcast conditions. However, when there is a "temperature inversion" in the area (frequently readily observable visually from the ground as a result of the smoke from the smelters), some of the shock waves which ordinarily would be deflected up into the air are instead deflected back down to the ground and often converge with the direct waves at Grantsville. A layer of unbroken clouds usually causes trouble in the same way. Shots should not be fired when these conditions for refraction and reflection of blast waves exist such as to cause high blast intensity at Grantsville or Tooele. This can be determined sometimes (on clear days) visually by observing the smoke conditions above the "International" Smelter across the valley or from around the point of the mountain. It may be advisable, however, to set up a communication system between the demolition range and someone at Grantsville so that firing can be terminated immediately whenever conditions are "bad" for firing. The most accurate system, but perhaps too costly, would be to make periodic temperature "soundings" of the atmosphere over the demolition range and conduct the demolition program in accordance with these findings.

2. The strongest shock observed in Grantsville during this investigation developed a pressure of approximately one pound per square foot, which is much too low to do damage to even a poorly constructed building. However, blast waves of this order or magnitude have been known to pull poorly held window panes from their frames, resulting, of course, in their being broken when they hit the ground.

3. When equal size shots are fired in all firing pits in the demolition range, those fired in pits No. 6 and No. 7 give the strongest shocks in Grantsville. Since these two pits are located in the upper end of the valley, the hills are not being used to their fullest advantage as barricades between the pits and the town. It is therefore advisable to relocate some of the firing pits, so as to take full advantage of these hills as natural barricades. This recommendation

was made verbally to T.O.D. authorities some time ago.

4. All observable components of the blast wave reach Grantsville 30-32 seconds after the shot was fired. Therefore, it is recommended, that the demolition shots be fired at intervals of approximately one minute.

5. Apparently the only annoyance factor to residents in the vicinity of the demolition range, associated with shots of 1000 lbs. (TNT equivalent) or less is the psycological factor. Since this is a real factor, especially to those people who do not understand the nature of air blast from detonating explosives, it is recommended that every possible effort be made (a) to educate the residents in this area in regard to blast wavesand their destructive potential and the nature of the work being conducted at the demolition range, and (b) to minimize in every way possible the noise and blast intensity from these blasts by following as closely as possible the above recommendations and those given in the work of Dr. Bell, Dr. Cox and others who have studied this problem.

Acknowledgement

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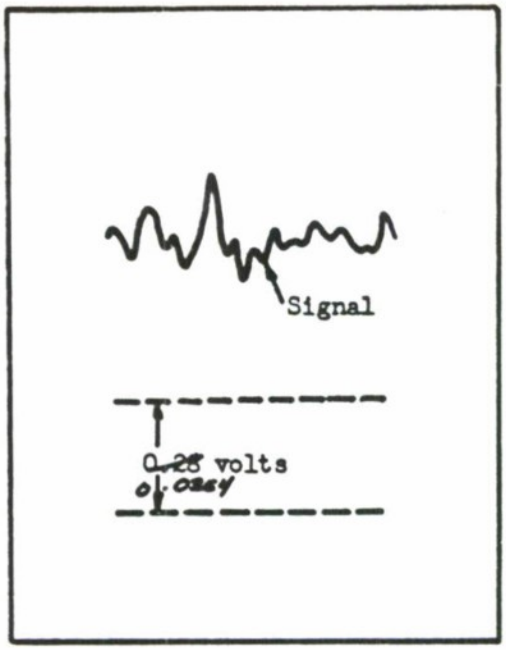


Figure 1

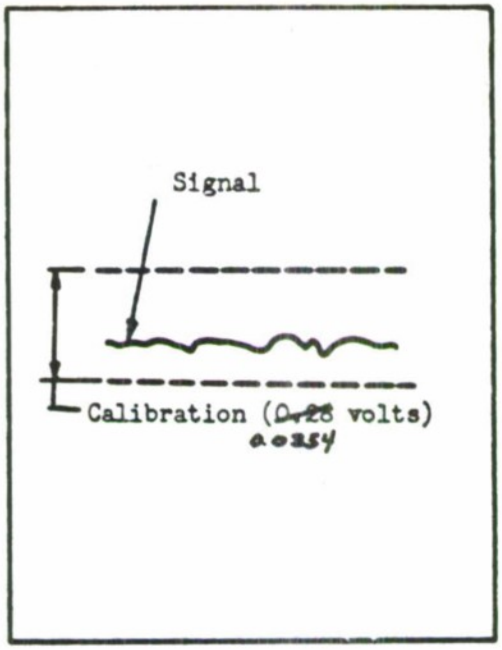


Figure 2

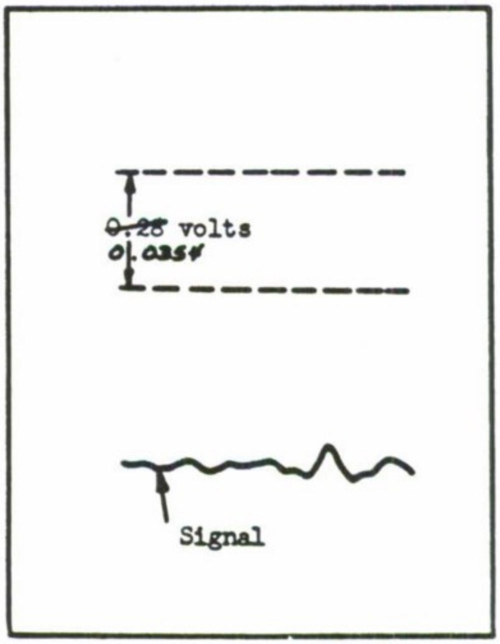


Figure 3

Tracings of oscillograph records of blast waves at Grantsville.

Figure 4: Calibration Curve

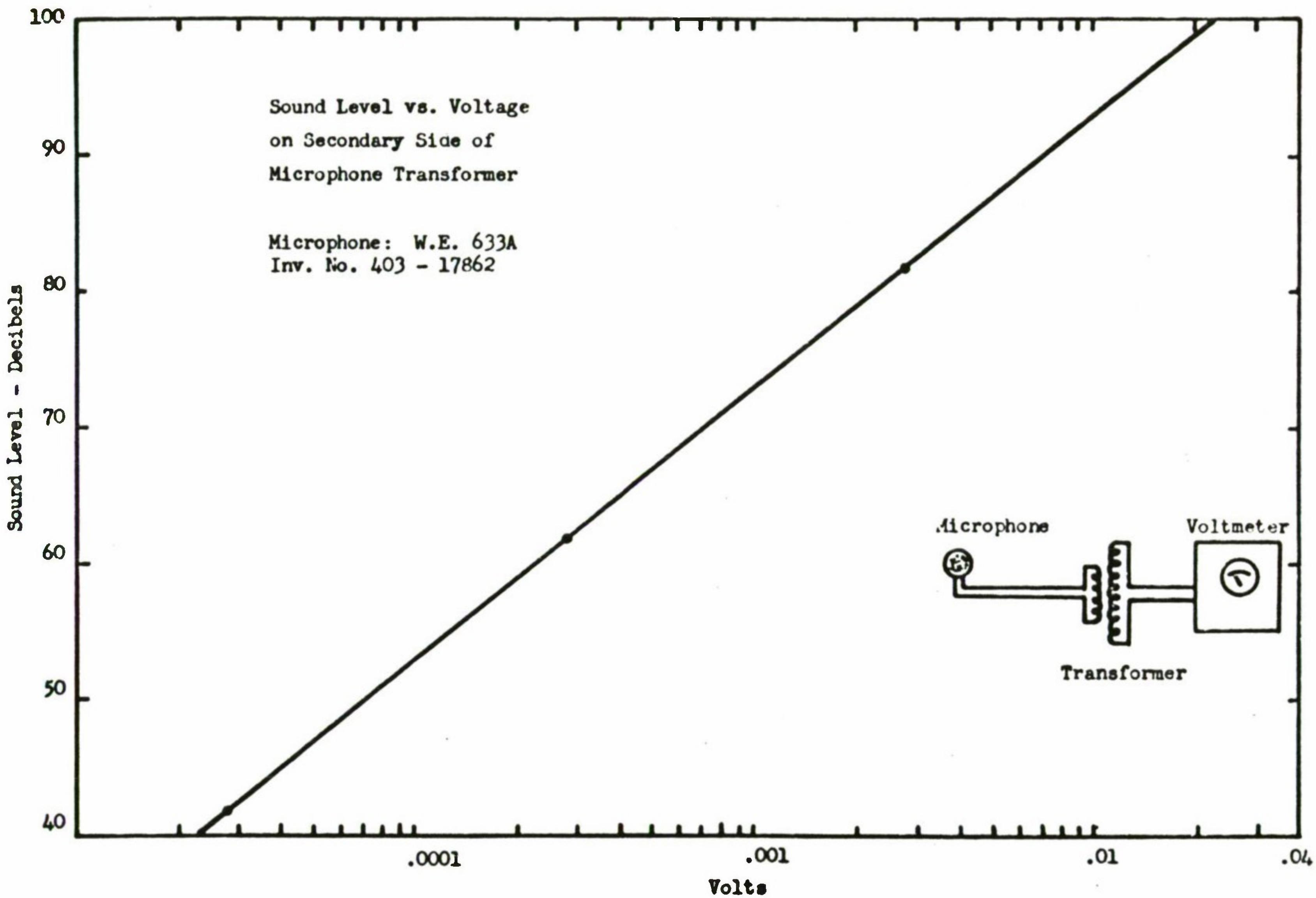
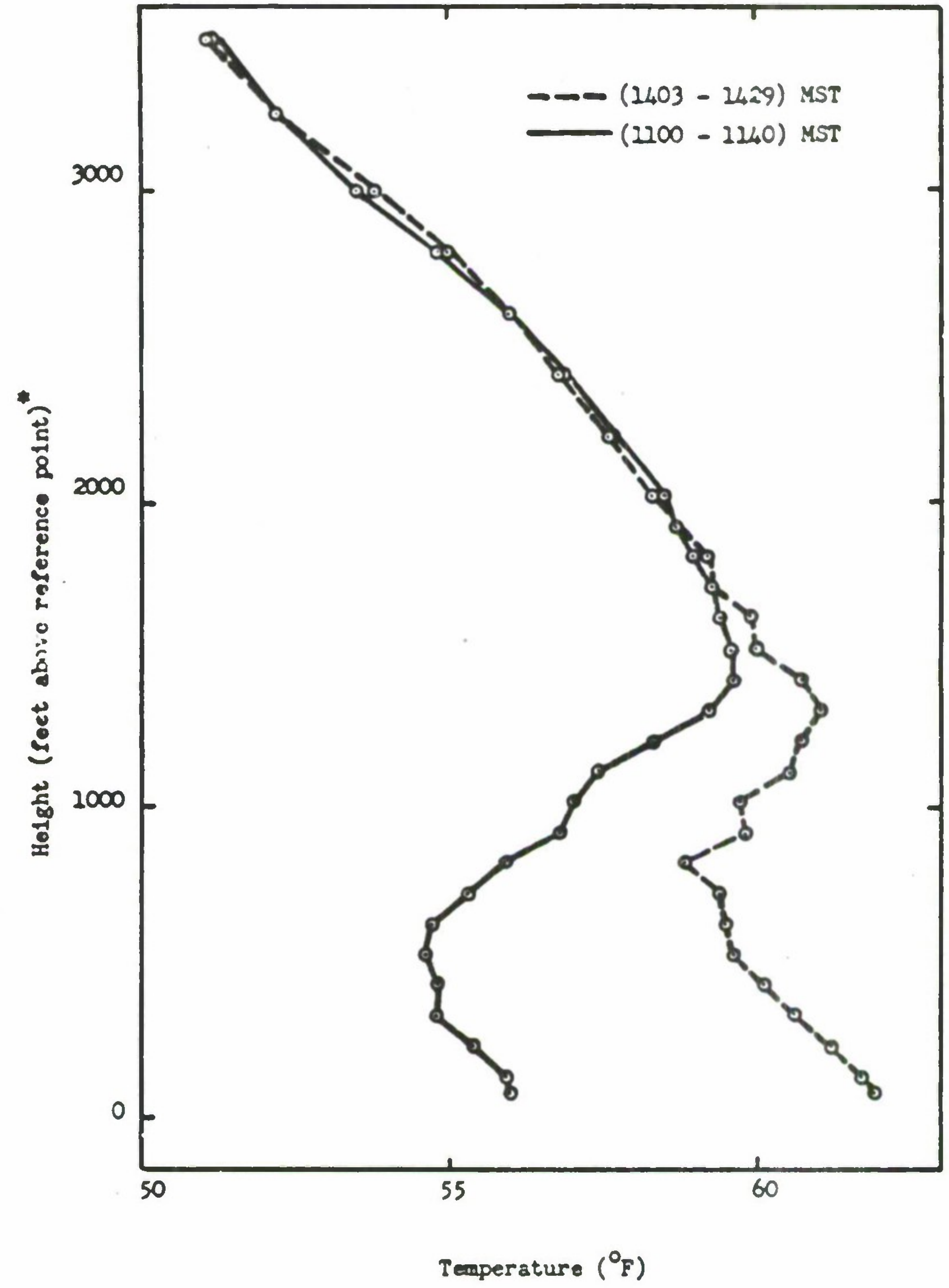


Figure 5: "Temperature Inversion", October 29, 1952



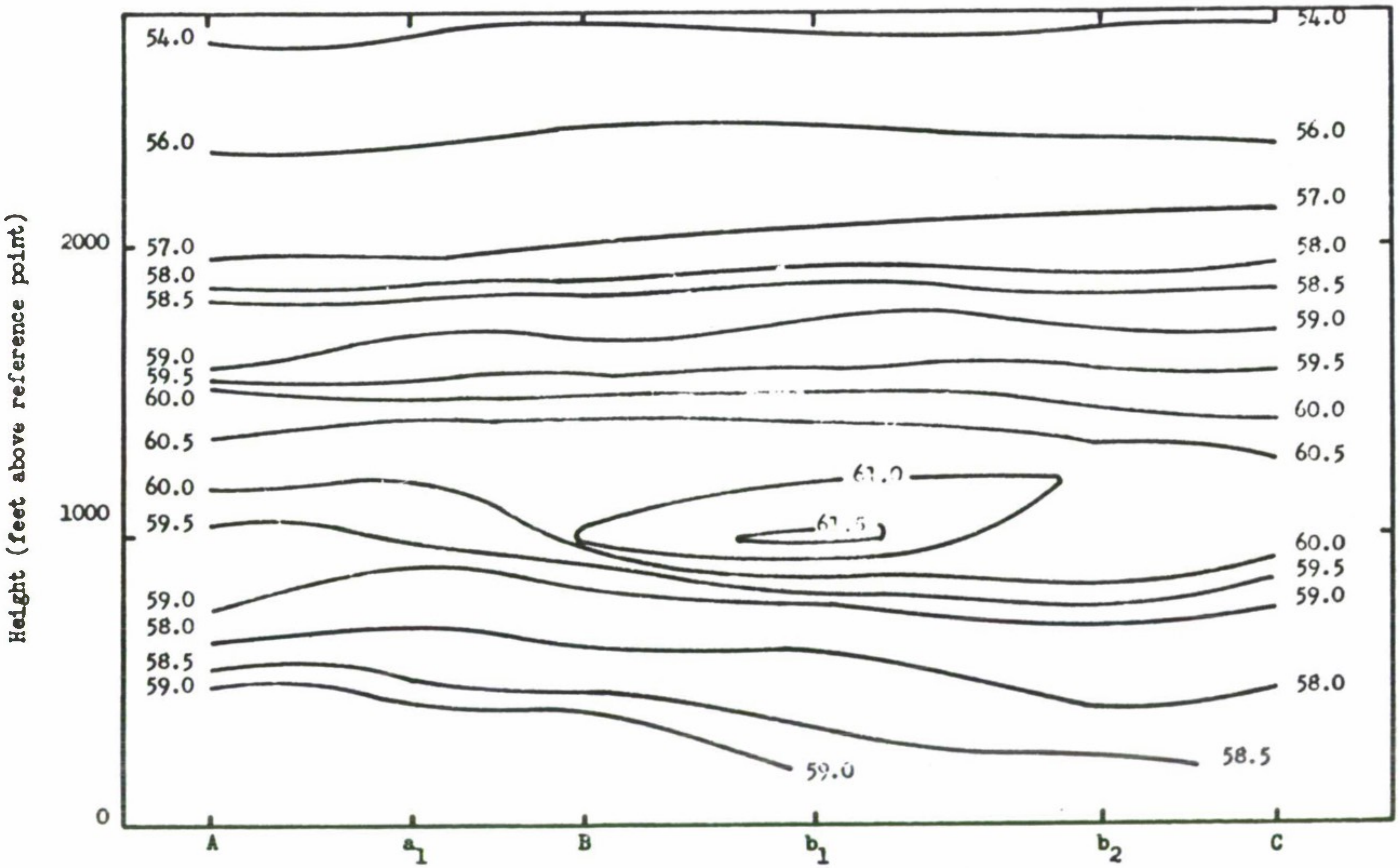
*Hill overlooking Munitions Area was reference point for altimeter setting

Time: (1100 - 1140) MST
(1403 - 1429) MST
Location: Gravel pit between Munitions Area and Grantsville

Height (Ft.)	Average Temp. (°F) (1100 - 1140) MST	Average Temp. (°F) (1403 - 1429) MST
50	56.0	61.9
100	55.9	61.7
200	55.4	61.2
300	54.8	60.6
400	54.8	60.1
500	54.6	59.6
600	54.7	59.5
700	55.3	59.4
800	55.9	58.8
900	56.8	59.8
1000	57.0	59.7
1100	57.4	60.5
1200	58.3	60.7
1300	59.2	61.0
1400	59.6	60.7
1500	59.6	60.0
1600	59.4	59.9
1700	59.3	59.3
1800	59.0	59.2
1900	58.7	—
2000	58.5	58.3
2200	57.7	57.6
2400	56.9	56.8
2600	56.0	56.0
2800	54.8	55.0
3000	53.5	53.8
3250	52.2	52.2
3500	51.2	51.1

Date: 29 October 1952
Location: Gravel pit between
Munitions Area and Grantsville

Figure 6: Temperature Cross Section (^{o}F)



Temperature Cross Section (^{o}F)

Position of Stations:

- A. Munitions Area - reference point for height
- B. Approximate position of gravel pit
- C. Approximate position of Grantsville
- a_1, b_1, b_2, approximate positions of intermediate points

Time: 1144 - 1227 MST
Date: 29 October 1952
Location: Area between Grantsville and T.O.D.

Temperature Cross Section (^oF)

Height (ft.)* Temperatures (^oF) at Various Stations

Height (ft.)*	A	a_1	B	b_1	b_2	C
200	60.2	59.3	58.9	58.8	58.6	58.4
400	59.7	59.3	59.0	58.3	58.0	57.7
600	58.2	57.6	57.7	58.0	58.4	58.6
800	59.3	58.6	58.8	59.2	59.9	59.2
1000	59.3	59.6	61.2	61.7	60.5	60.6
1200	60.1	60.0	60.6	60.9	61.0	60.8
1400	60.3	60.5	60.6	60.5	60.2	59.9
1600	58.8	59.1	59.2	59.5	59.4	59.4
1800	58.6	58.9	58.7	59.0	58.7	58.6
2000	56.7	56.7	57.0	57.3	57.4	57.7
2500	55.7	55.6	55.8	55.6	55.4	55.2
3000	52.0	52.2	52.3	52.4	52.7	53.0
3500	50.8	51.0	51.0	51.2	51.4	51.4

* Hill overlooking munitions area was reference point for altimeter setting.

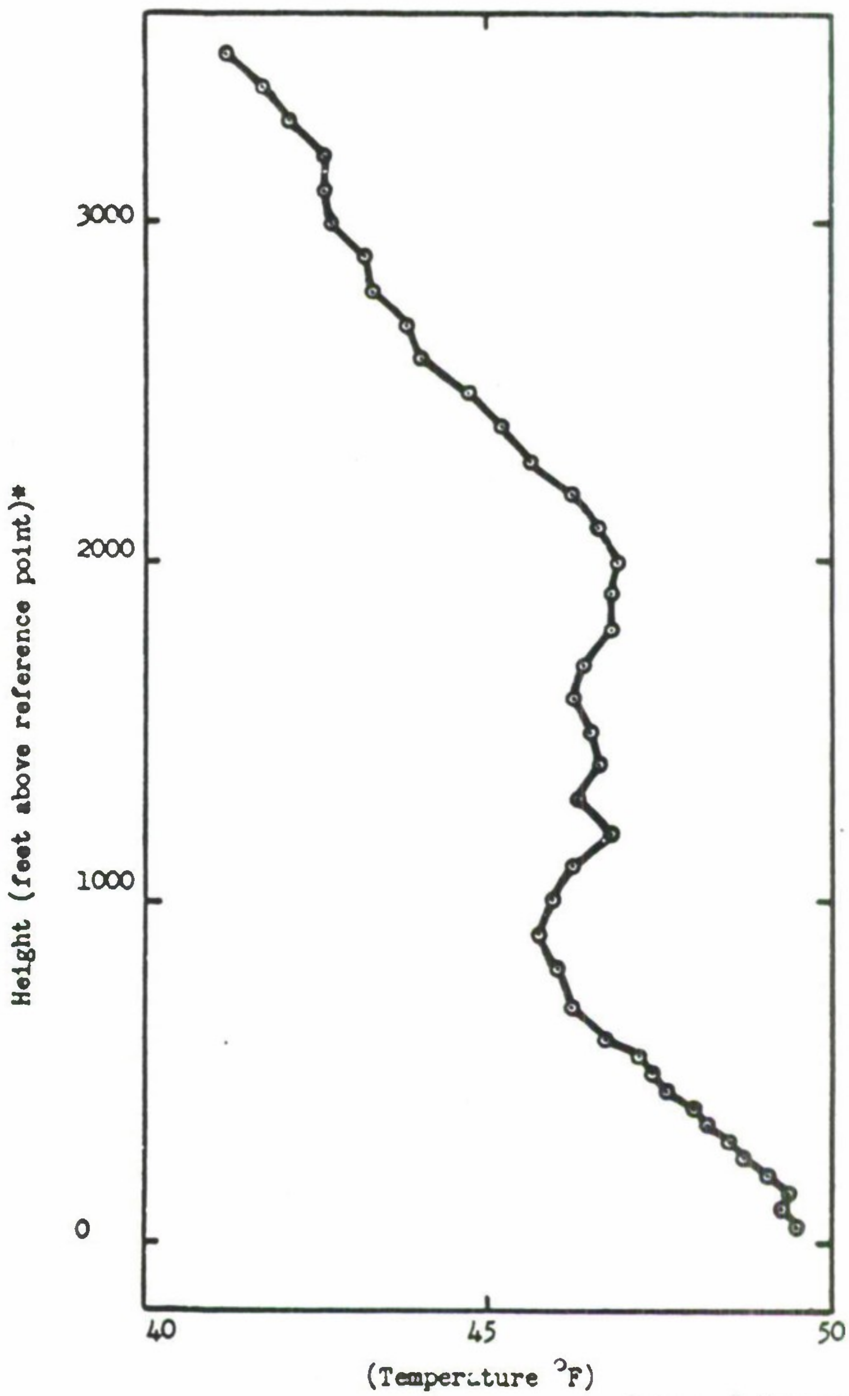
A - Munitions area
B - Gravel pit
C - Grantsville
a, b, and b_2: Intermediate points where data was taken.

Date: 29 October 1952

Location: Area between Munitions Point and Grantsville

Time: 1144 - 1227 MST

Figure 7: Slight "Temperature Inversion"



Date: 7 November 1952
Time: (1311 - 1334) MST
Location: Gravel pit between Munitions Area and Grantsville

*Hill overlooking Munitions Area was reference point for altimeter setting

Height (ft.)	Average Temp. (°F) (1311 - 1334) MST
50	49.5
100	49.3
150	49.4
200	49.1
250	48.7
300	48.5
350	48.2
400	48.0
450	47.6
500	47.4
550	47.2
600	46.7
700	46.2
800	46.0
900	45.7
1000	45.9
1100	46.2
1200	46.8
1300	46.3
1400	46.6
1500	46.5
1600	46.2
1700	46.4
1800	46.8
1900	46.8
2000	46.9
2100	46.6
2200	46.2
2300	45.6
2400	45.2
2500	44.7
2600	44.0
2700	43.8
2800	43.3
2900	43.2
3000	42.7
3100	42.6
3200	42.6
3300	42.1
3400	41.7
3500	41.2

Date: 7 November 1952
Location: Gravel pit between
Munitiona Area and Grantsville

Figure 8: Sound Intensity vs. Distance from Demolition Range

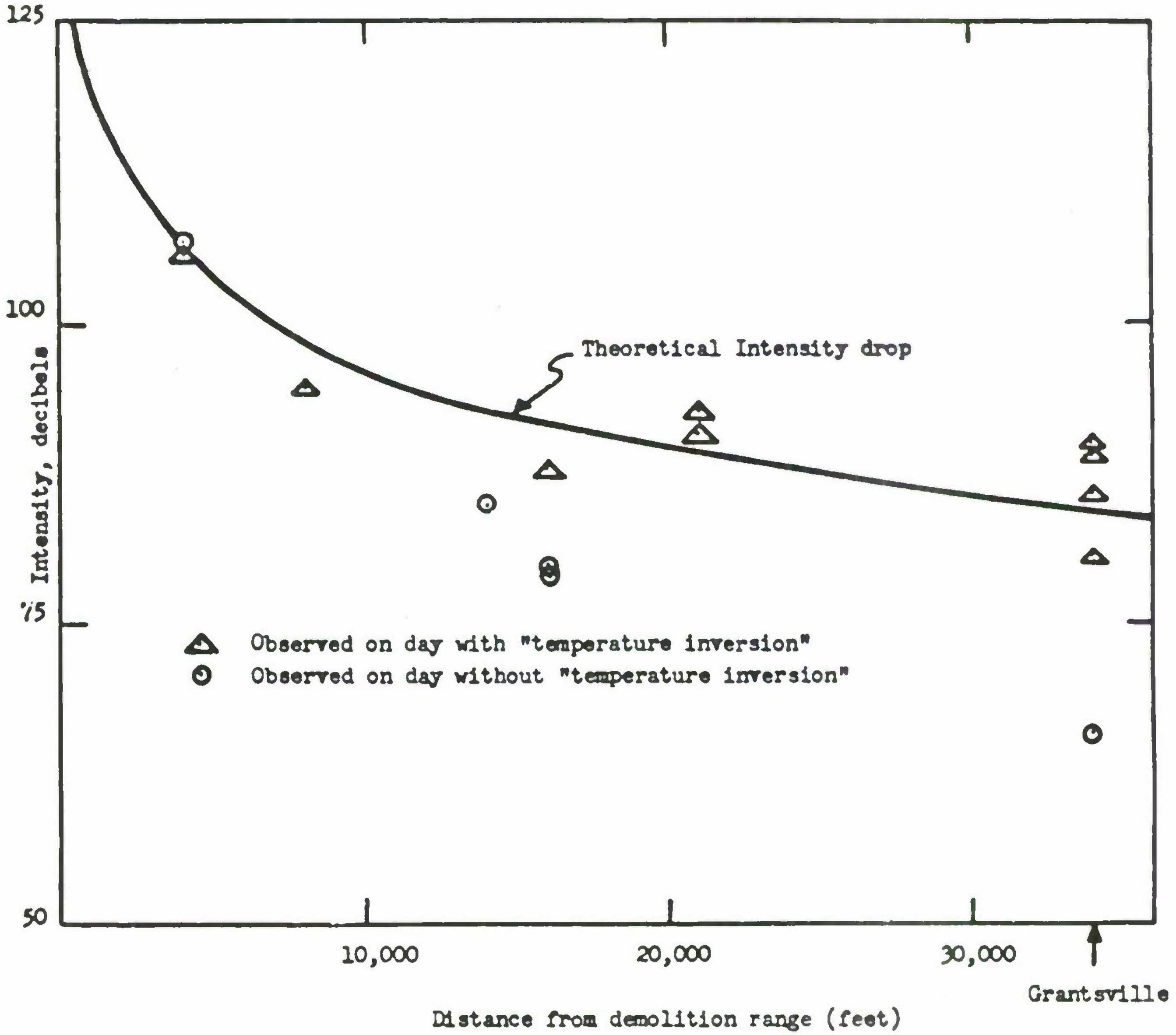


Figure 9: Average Damage Limits from a Thousand Pound Explosion of TNT